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THE CANMET FERRIC CHLORIDE LEACH PROCESS: CEMENTATION OF COPPER AND SILVER ON IRON

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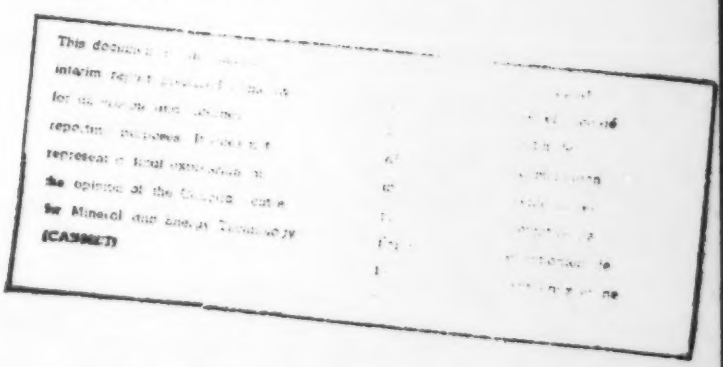

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FERRIC CHLORIDE LEACH PROCESS: CEMENTATION OF Cu AND Ag ON IRON

by

D.Y. Shimano* and G.F. Wallingford**

ABSTRACT

Cu and Ag values were recovered from zinc chloride leach liquors by a two-stage cementation reaction using iron wire and iron powder. Cu and Ag concentrations were reduced from 1250 and 33 mg/L, respectively, to the process specification of <1 mg/L each. The preferred cementation conditions were as given below.

Stage One: 50°C, N_2 sparging, dynamic mixing
925 kg Fe (wire)/tonne of concentrate
Solution pH, $0.5 \leq pH \leq 1.5$
Retention time 20 min.

Stage Two: 50°C, N_2 sparging, dynamic mixing
6.2 kg Fe (powder)/tonne of concentrate
Solution pH, $0.5 \leq pH \leq 1.5$
Retention time 20 min.

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In stage one >98.5% of the soluble Cu and Ag values were recovered in a dense, granular cement product, which contained 54.1% Cu, 2.1% Ag and 0.39% Fe. The small quantities of this complex solid product, did not permit complete analysis. The second stage cement, for recycle to stage one, contained 83.3% Fe, 1.0% Cu and 0.2% Ag. Over two stages, the iron consumption was between 2 and 3 g/L Fe, whereas the HCl consumption was negligible. The iron reagent consumption was estimated at >1.1/kg of zinc.

Keywords: iron cementation, chloride media

INTRODUCTION

CANMET is actively investigating and promoting a $FeCl_3$ leach (FCL) process to recover Pb, Zn, Cu and Ag from a complex pyritic bulk flotation concentrate. New Brunswick has abundant reserves of complex base metal sulphide ores, many of which cannot be economically exploited using conventional processing routes. With little new base metal capacity coming on stream in the short-term, it would be advantageous to develop further the CANMET FCL process for increased recoveries from mineralogically complex pyritic bulk flotation concentrates.

The proposed FCL process (Fig. 1) included a lead cementation and an aqueous electrowinning operation for Cu/Ag and Zn recovery, respectively. Pb was initially selected as the cementation agent since a readily available source of Pb metal would be available after reduction of the $PbCl_2$ intermediate product. The cementation operation is required to produce a high value Cu/Ag cement product and a Zn solvent extraction feed aqueous containing <1 mg/L each of Cu and Ag. Previous work established that very low metallic impurity concentrations of <1 mg/L, were required to permit good quality cathode Zn to be electrowon at high current efficiencies (1).

Pb cementation was evaluated at both bench (2) and pilot plant scale (3) using a 3.5 times stoichiometric Pb excess based on Cu and Ag. Further investigations at twice the stoichiometric excess of Pb produced solutions containing <1 mg/L each of Cu and Ag (4). The cement product, however, was not of high value and would require further processing to reduce the Pb level from 60% to <10% (2).

Iron cementation of Cu and Ag was investigated as an alternative to Pb cementation. Both granular iron and iron dust at 3.1 and 2.5 stoichiometric excess were effective in removing Cu and Ag from chloride liquors (5,6). The cement produced using iron dust contained 45% Cu, 34% Fe, 1.7% As, 1.7% Sb, 1.2% Ag and 0.5% Pb.

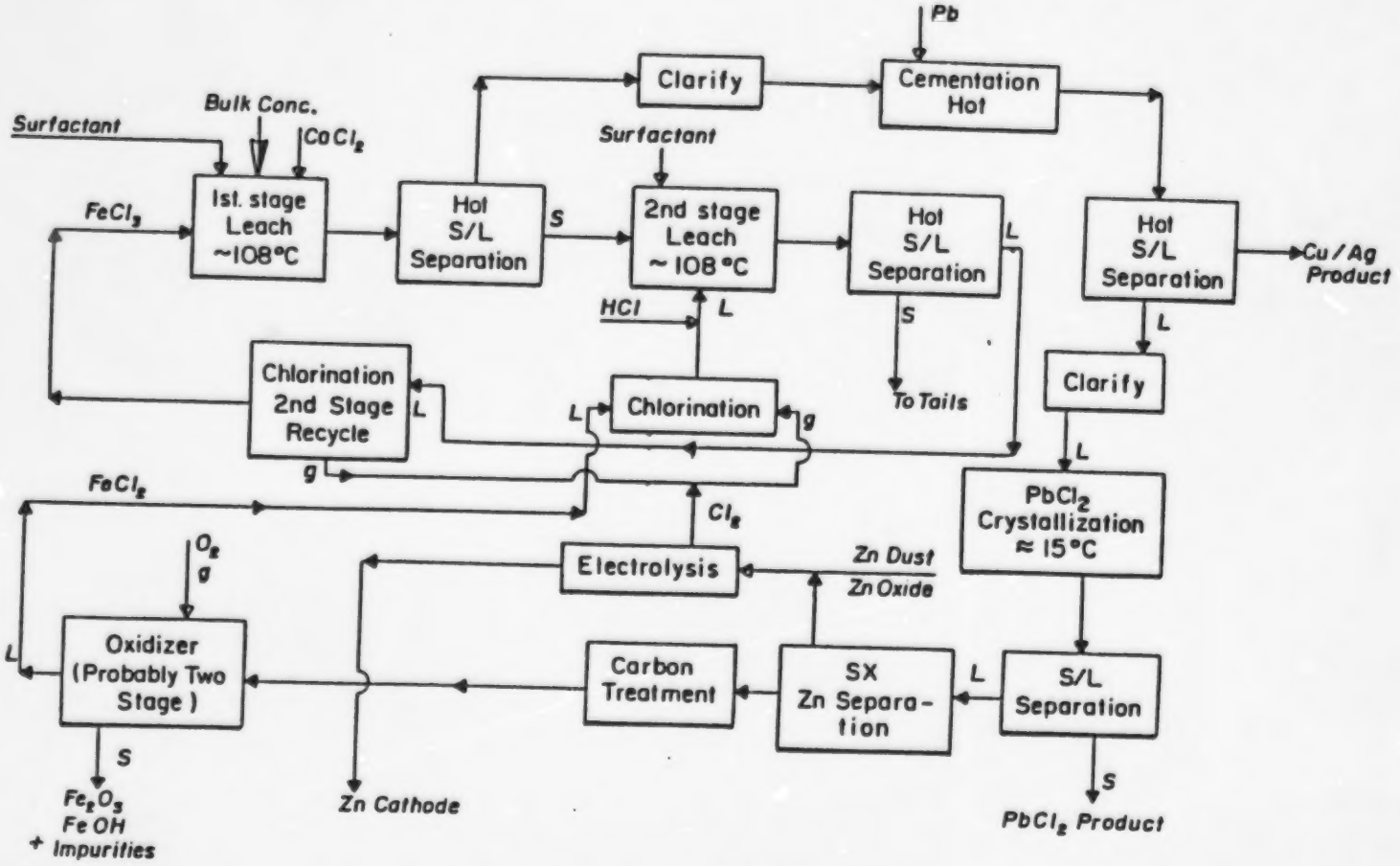

Figure 1. Integrated $FeCl_3$ Leach Process Pilot Plant Flowsheet

Based on the promising Fe cementation studies, a modified FCL process flowsheet was proposed (Fig. 2) incorporating a bleed stream for iron control and impurity purge.

The most probable reactions of soluble copper and silver on iron are as follows:

$$CuCl_2 + Fe \rightarrow Cu + FeCl_2 \quad [1]$$

$$2AgCl + Fe \rightarrow 2Ag + FeCl_2 \quad [2]$$

$$2FeCl_3 + Fe \rightarrow 3FeCl_2 \quad [3]$$

$$2HCl + Fe \rightarrow FeCl_2 + H_2 \quad [4]$$

$$2FeCl_3 + Cu \rightarrow CuCl_2 + 2FeCl_2 \quad [5]$$

Reaction [1] is the desired cementation reaction and according to the stoichiometry, 880 g of Fe would produce 1 kg of Cu. In actual practice (using sulphate media) the Fe consumption ranges from 1.5 to 2.5 kg Fe/kg of Cu (7). The excess consumption of iron has been attributed to the reactions [3,4,5]. In sulphate media, the analogue to reaction [4] has been found to be kinetically slower than reaction [1] and reaction [4] can be slowed by reducing the contact time (7).

The present study focusses on the cementation behaviour of copper and silver on iron at 90, 25 and 50°C. The cementation at 90°C simulates cementation prior to lead chloride crystallization (Fig. 1 type flowsheet), whereas the other two temperatures represent cementation after lead chloride crystallization (Fig. 2 type flowsheet). To approximate industrial practice, batch and continuous solid/liquid contactors were studied using iron in both the wire and powder form. The influence of acid concentration on Cu/Ag cementation, and on iron and acid consumption were investigated. The objective of the study was to assess the utility of Cu/Ag cementation on iron.

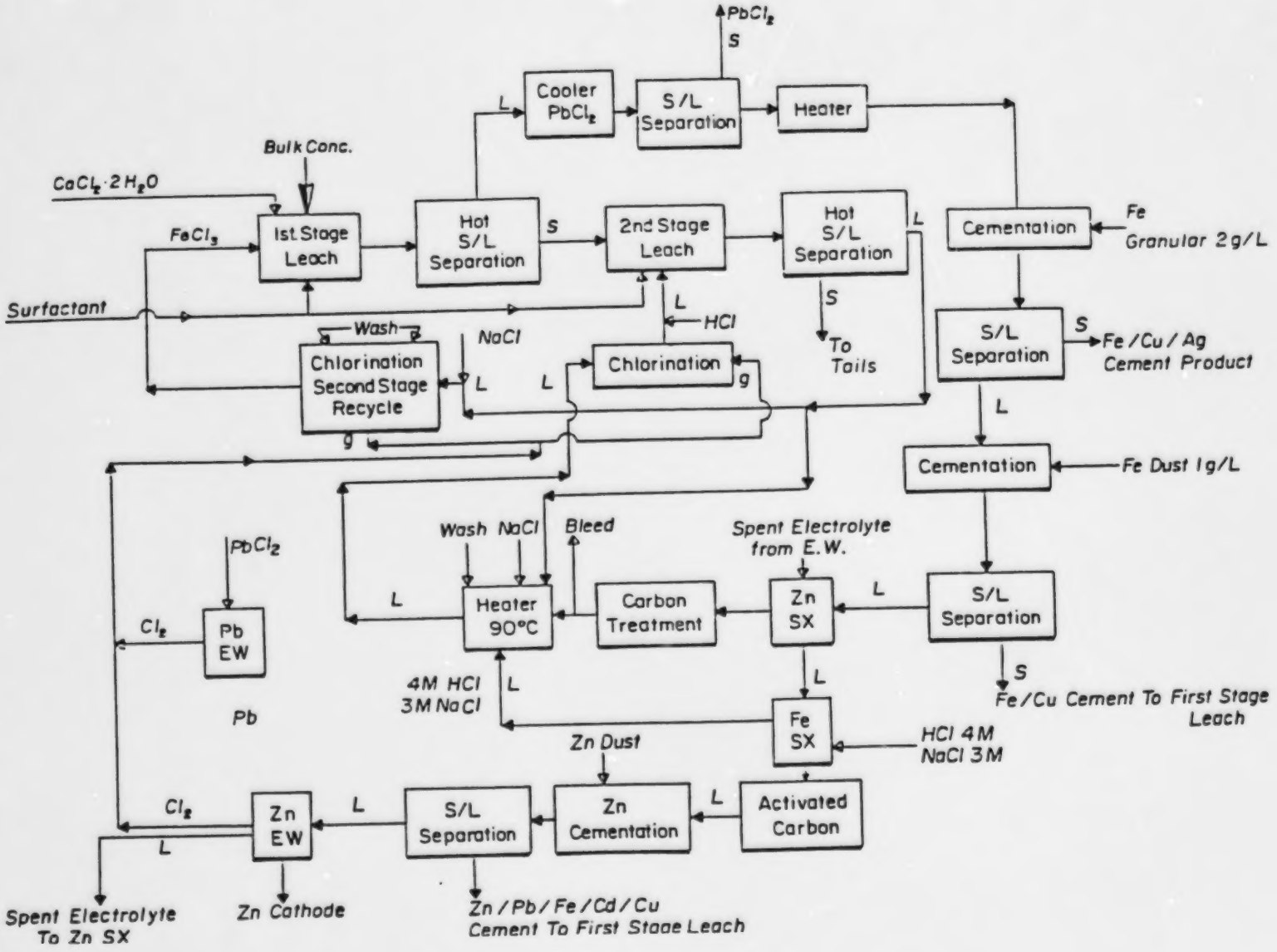

Figure 2 - Modified $FeCl_3$ leach process pilot plant flowsheet

EXPERIMENTAL

The cementation feed solutions were usually leach liquors produced after removal of $PbCl_2$ via crystallization at 25°C (Fig. 2). The filtered liquors typically contained in g/L: Na 65, Fe 56, Zn 50, HCl 1 to 2, Ca 1.4, Cu 1.0, As 0.17, Ag 0.04, Cd 0.04, Sb 0.03 and Ni 0.03. The pH was adjusted by adding concentrated HCl to the leach liquor, followed by $PbCl_2$ crystallization and filtration of the cementation feed liquor. Where synthetic liquors were used, the composition was similar to the Na, Fe, Cu and Ag concentrations given above.

The chemical and physical analysis for the Fe samples used were as shown in Tables 1 and 2. The iron wire was considered as being equivalent to high quality scrap iron.

Table 1. Fe Samples Chemical Analysis

Sample	%							
	C	S	P	Mn	Si	Co	Cr	Ni
Wire	0.046	0.010	-	0.26	<0.01	0.86	0.068	0.033
Powder*	0.006	0.006	0.025	-	-	-	-	-

*Chemical analysis as supplied by the manufacturer

Table 2. Fe Samples Physical Analysis

Fe Wire		Fe Powder		
Diameter mm	Surface Area[1] m^2/kg Fe	Size Fraction[2] μm	Distribution[2] wt %	Surface Area[3] m^2/kg Fe
1.5	0.14	+250	trace	26.4 (total)
		+212	0.1	
		+150	7.8	
		+106	23.9	
		+ 74	22.9	
		+ 63	7.9	
		+ 45	13.5	
		- 45	23.9	

1) The Fe wire surface area was calculated assuming a constant diameter of 1.5 mm
2) Data as supplied by the powder manufacturer
3) The Fe powder surface area was calculated using the data (2) and assuming that the particles were perfect spheres

The cementation reactions were studied using both batch and continuous type contactors. The batch tests at 50°C were carried out in two stages using mechanically agitated beakers as reaction vessels, with heat provided by hot plates. Nitrogen was injected into the solution to displace dissolved oxygen and to maintain non-oxidizing conditions during cementation. In stage one, the leach liquor at temperature was contacted with an iron wire/base plate assembly. The base plate consisted of a circular, concentrically perforated plastic plate. Iron wire of fixed length, when added to the bottom plate, formed a vertical "forest" of Fe around the perimeter of the area swept by the stirrer. Nitrogen was delivered at the plate surface to improve mixing and possibly to dislodge Cu/Ag rich material from the iron surface.

Periodically, solution samples were withdrawn and filtered. At the completion of the desired retention time, the remaining solution was filtered on a Buchner funnel. The cement product was removed and combined with the filtered solids. The combined solids were washed with hot water, dried and weighed. Fresh Fe wire was added to the base plate to maintain a constant weight of Fe between tests.

In stage two, the stage one filtrate was heated to the desired temperature, and a single addition of Fe powder made. The combination of N_2 sparging and vigorous agitation ensured that the Fe particles were in suspension. Periodically, solution samples were taken and handled as described above.

Single stage tests at 90°C were conducted batchwise using iron powder to treat leach liquors. The reaction vessels were mechanically agitated with N_2 sparging. Periodically, solution samples were withdrawn, filtered and handled as described above.

Continuous cementation was studied at 25°C using a fixed bed type contactor. The columns contained 100-150 g of Fe wire and were operated at a bed volume (BV) of 150 mL using synthetic leach liquor as the feed. Assuming plug flow through the

contactor, a 6.4 BV/h flow rate was equivalent to a 9 min solution residence time. All tests utilize two identical contactors in series. The stage one cemented solution were periodically collected, filtered and analyzed prior to feeding the stage one composite to stage two.

Solid and solution samples were analyzed using atomic abosrption methods.

RESULTS AND DISCUSSION

A. Single Stage Cementation at 90°C

Leach liquors at pH 0.5 and rich in soluble lead were cemented at 90°C with iron powder. At $\geq$ 3.8 times stoichiometric iron excess (based on Cu and Ag), the desired reactions [1] and [2] proceeded rapidly and essentially to completion (Table 3 and Fig. 3). The process specification of <1 mg/L each of Cu and Ag was reached after a 20 min retention time. The deleterious reaction [5] on the redissolution of cemented Cu was not observed.

The data also indicated that the undesirable reactions [3] and [4] were also ongoing during the cementation of Cu and Ag. At a high iron addition (24.2 kg iron/tonne concentrate), the Fe^{+3} concentration was reduced from 1100 to $\leq$ 700 mg/L during a 15 min period (reaction [3]). during the 15 min contact, at 90°C, the solution pH increased from 0.46 to 0.65 (reaction [4]).

A noteworthy characteristic of iron cementation at 90°C was the high level of Pb contamination of the cement product (Table 3). Such a product would require extensive Pb reduction treatment, prior to sale as a Cu/Ag concentrate containing $\leq$ 10% Pb (2).

B. Continuous Two Stage Cementation at 25°C

A processing option was investigated where low cost Fe(wire) and ambient reaction temperatures (25°C) were utilized. The results showed that the Cu kinetics were not sufficiently rapid at 25°C to produce acceptable (<1 mg/L each Cu and Ag)

Table 3. Single Stage Cementation at 90°C, pH 0.5

Cement agent		Cemented leach liquor					Cement product, assay %					
Type	Addition level kg/tonne	Cu mg/L	Ag mg/L	Fe^{+3} mg/L	pH	Contact time min	Cu	Ag	Pb	As	Sb	Fe
Fe powder	24.2[1)]	840	31	1100	0.46	0						
		1	0.4	100	-	5						
		1	0.4	500	-	10						
		1	0.4	700	0.65	15	7.6	0.37	77	1.2	0.4	1.6
Fe powder	15.4[2)]	730	37	400	0.50	0						
		14	1	800	-	5						
		5	0.6	1500	-	10						
		1	0.4	200	-	15						
		0.9	0.4	600	0.58	20	7.9	0.40	69	1.4	0.6	n.a.

[1)]4.7 times excess stoichiometry (based on Cu and Ag)
[2)]3.8 times excess stoichiometry (based on Cu and Ag)
n.a. - not available

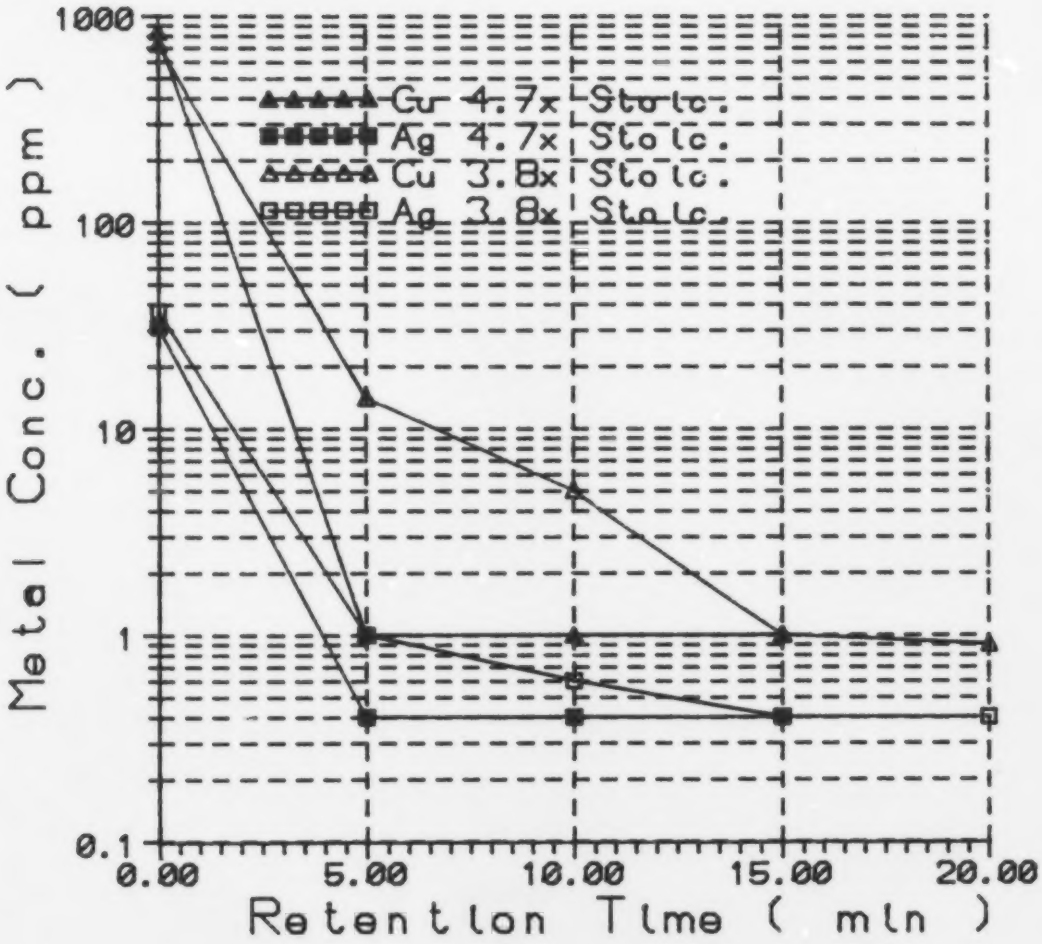

Figure 3 . Fe Cementation 90 C , pH 0.5

solutions. In stage one, pH 0.54 and 925 kg Fe/tonne (with an equivalent iron surface area of 1.3×10^2 m^2/tonne), the Cu and Ag concentrations were reduced from about 1000 and 30 mg/L to 25 and 6 mg/L each (Fig. 4). In stage two, the cementation reactions remained sluggish and the composite feed solution at 89 ppm Cu and 4 ppm Ag to 34 ppm and 2 ppm, respectively.

The final Cu concentrations were mo t dependent on the feed solution acidity. A decrease in the feed pH from 0.54 to 0.33 resulted in an order of magnitude difference (25 vs 250 ppm) in the stage one Cu concentration at 925 kg Fe/tonne. The final Cu concentrations were less dependent on surface area at pH 0.5, where a 33% decrease in surface area (1.3×10^2 to 8.6×10 m^2/tonne), resulted in a 5 fold increase in the final stage one Cu concentration (25 to 120 mg/L Cu).

The cement product was finely sized and tended to form agglomerated flocs of low density. These slimes are undesirable as they tended to blind filtration surfaces. Similar low density cements were formed during iron cementation in launders (8).

C. Two Stage Fe Cementation at 50°C

(a) Influence of pH

(i) Stage One

Batch tests were conducted using leach liquors at various pH levels and the Fe wire/base plate assembly. The stage one conditions were as below:

Reaction Vessel:	Beaker with dynamic mixing and N_2 sparging.
Reaction Temperature:	50 ± 5°C
Reaction Time:	30 min
Fe Wire Addition:	925 or 1080 kg/tonne ($1.3 - 1.5 \times 10^2$ m^2 surface area/tonne)

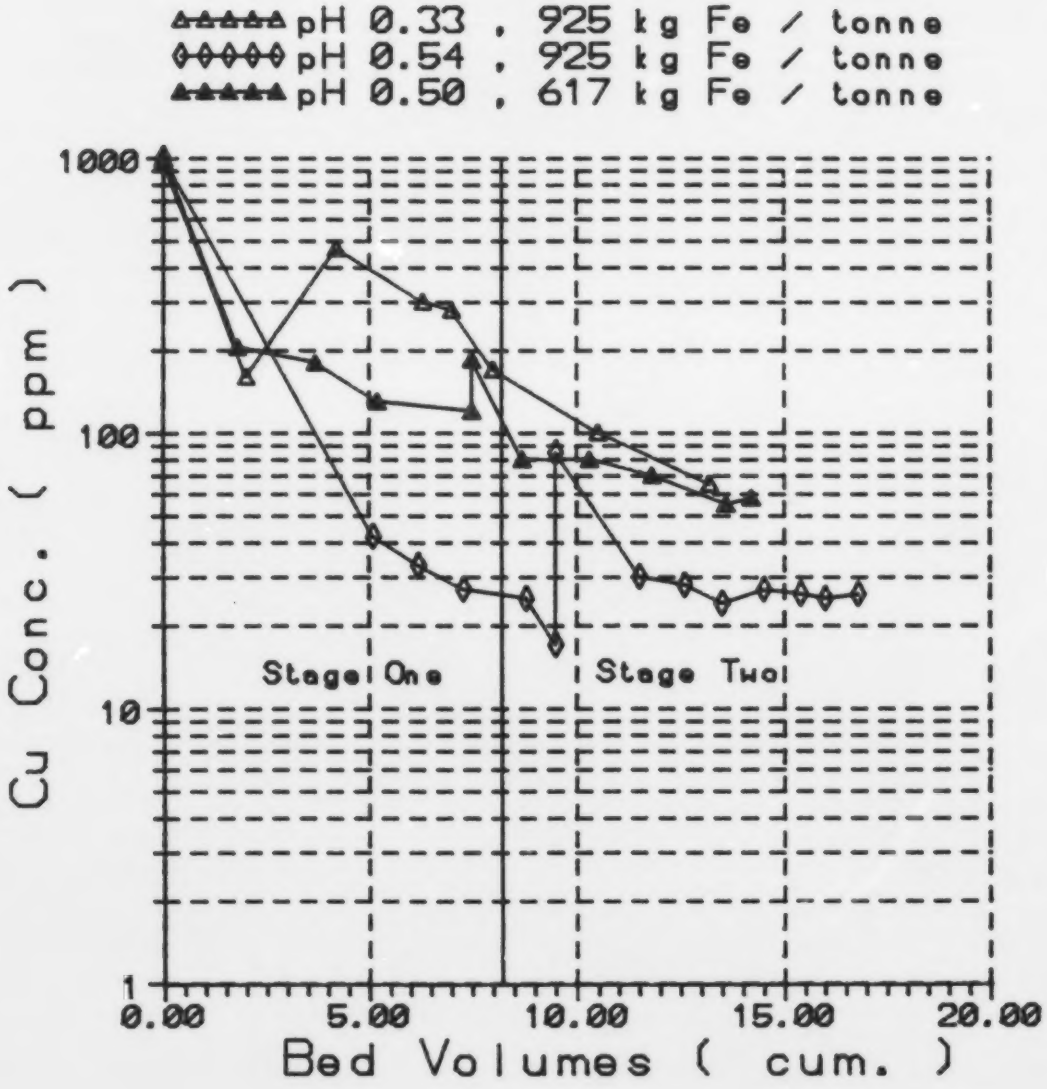

Figure 4. Two-Stage Fixed Bed Fe Cementation 25 C

The extent of Cu cementation on iron wire was dependent on the solution pH. Lower final Cu concentrations were achieved at higher solution pH. As shown in Table 4, at pH 2.0, the Cu concentration was reduced from 1320 to 2 mg/L using 1080 kg Fe/tonne of concentrate. At pH 0.9 to 2.0, the final Cu concentration was $\leq$ 6 mg/L, with $\geq$ 99.5% Cu recovery. At higher acid concentrations (pH 0.31 to 0.55) the final Cu concentration was comparably higher, at about 12 mg/L Cu and 99.0% recovery.

Table 4. Influence of pH on Stage One, Fe cementation at 50°C

pH	Fe addition kg/tonne	Retention time min	Cemented leach liquor concentration					
			Cu mg/L	Ag mg/L	As mg/L	Sb mg/L	Cd mg/L	Bi mg/L
0.31	1080	0	1460	37	120	-	-	-
0.34		30	9	-	32	-	-	-
0.55	925	0	1010	31	180	55	50	32
0.47		30	14	0.4	140	7	49	9
0.94	925	0	1200	38	190	58	57	36
		30	6	0.4	140	10	55	9
2.0	1080	0	1320	26	130	36	44	-
		5	63	0.5	-	-	-	-
		10	6	0.5	-	-	-	-
		15	6	0.5	-	-	-	-
		20	5	0.5	-	-	-	-
		30	2	0.4	60	12	43	-

The cementation of Ag was independent of pH, and relatively fast. At pH 0.55 to 2.0, the Ag concentration was consistently lowered to 0.4 mg/L within 30 min. At pH 2.0, the Ag concentration decreased from 26 mg/L to 0.5 mg/L within 5 minutes.

The concentration of deleterious trace impurities such as As, Sb, Bi and Cd were also monitored. At 50°C, on average 45, 79 and 74% of the soluble As, Sb and Bi values present in the leach liquor were cemented out of solution. The data did not

indicate a trend towards lower final trace metal concentrations with increased solution pH. It is noteworthy that Cd was not cemented on iron wire, under the conditions studied.

(ii) Stage Two

Leach liquors after treatment in stage one, were contacted batchwise under the stage two conditions below:

Reaction Vessel:	Beaker with dynamic mixing and N_2 sparging
Reaction Temperature:	50 ± 5°C
Reaction Time:	30 minutes
Fe addition:	6.2 kg Fe powder/tonne (1.6×10^2 m^2 surface area/tonne)

The results were as shown in Table 5. The stage two operation was essentially a polishing step where low concentrations of Cu and Ag ($\leq$ 14 and 1 mg/L) were reduced in the presence of relatively large concentrations of As and Sb (>60 and >70 mg/L). Under all pH's (0.47 to 2.0), the process specifications of <1 mg/L each of Cu and Ag were achieved. The data (Table 5) indicates that lower final Cu and Ag concentrations of about 0.5 mg/L each are achievable where the leach liquor pH is 1.50 or greater.

The two stage cementation operation did not consume appreciable acid, as shown by the pH data in Tables 4 and 5. In stage two, the solution pH increased marginally from 1.65 to 1.78 during a 30 min contact at 50°C. Less acid was consumed at 50°C in a two stage cementation that at 90°C in a single stage cementation (Table 3).

Table 5. Influence of pH on Stage Two, Fe cementation at 50°C

pH	Fe addition kg/tonne	Retention time min	Cemented leach liquor concentration					
			Cu mg/L	Ag mg/L	As mg/L	Sb mg/L	Cd mg/L	Bi mg/L
0.47	6.2	0	14	0.4	140	7	49	9
0.47		30	0.9	0.4	130	10	49	9
1.50	6.2	0	2.0	0.9	70	11	36	-
1.44		30	0.4	0.5	72	9	36	-
1.65	6.2	0	2.0	0.4	89	12	-	-
1.78		5	1.0	0.3	-	-	-	-
1.79		10	0.8	0.3	-	-	-	-
1.80		15	0.4	0.3	-	-	-	-
1.84		20	0.4	0.3	-	-	-	-
1.77		30	0.4	0.3	75	11	-	-
2.0	6.2	0	1	0.4	60	13	-	-
-		10	1	0.5	-	-	-	-
		20	0.8	0.5	-	-	-	-
2.0		30	0.6	0.4	<1	10	-	-

The concentrations of As, Sb, and Bi were not significantly reduced at pH 0.47 to 1.65. Significant As removal was observed only at pH 2.0, where <1 mg/L As remained in solution after 30 min retention time at 50°C. Cd was not cemented out of solution under any of the conditions studied.

(b) **Nature of Cement Products**

The physical nature of the stage one cement product was dependent on the degree of agitation during cementation. Under dynamic conditions (mechanical agitation in beakers) the cement product tended to be granular and usually dislodged from the iron wire surfaces with agitation. In a fixed bed, with less than dynamic conditions (assumed plug flow) the cement product adhered to the iron wire as a sponge. The undesirable sponge cement has been observed in cementation launders where the thixotropic solids were difficult to dewater and contained up to 90% moisture (8).

The cement products obtained from pH 0.31 to 2.0 leach liquors, under dynamic conditions, were blended and assayed as follows:

Stage one: 54.1% Cu, 2.10% Ag, 0.39% Fe, 0.14% Na, 0.12% Zn, 240 ppm Ca, <6 ppm Cd.
Stage two: 83.3% Fe, 0.99% Ag, 0.20% Na, 0.15% Ag.

The stage one cement was obviously a complex material. The small quantities obtained from these bench scale tests, did not allow for exhaustive elemental analysis. On the basis of As and Sb solution assays and the Ag removed, the expected As and Sb content would be 4.5% As, 1.7% Sb - stage one product and 2.5% As, 0.3% Sb - stage two product.

The iron wire cement product was of higher Cu and Ag grade (54.1% Cu and 2.10% Ag vs 45% Cu and 1.2% Ag) as compared to a previous cement using iron powder (6). Additional tests will be required to confirm the As and Sb content in the iron wire cement product. The stage two product at 83% Fe, will be recycled to stage one.

(c) Solution Stability

Post cementation solutions were stable with respect to Fe^{+2} oxidation, hydrolysis and Fe precipitation. For example, a treated solution containing 1000 mg/L Fe^{+3}, 0.4 mg/L Cu and 0.3 mg/L Ag at pH 1.7 and +304 mV had a pH and emf values of 1.5 and +333 mV respectively, 6 days after treatment. The solution was cloudy, but no Fe precipitation was visible.

(d) Two Stage Fe Cementation from Synthetic Solutions

Batch tests at 50°C were conducted at pH 1.0 using a synthetic feed solution containing 50 g/L Zn, 40 g/L Fe^{+2} and 1.4 g/L Cu. The operating conditions were adjusted using an increased charge of low cost iron wire in stage one, and a decreased charge of high cost iron powder in stage two. The

stage one and two iron additions were 1300 kg wire/tonne and from 1.6 to 6.2 kg powder/tonne. Both stages were conducted in mechanically agitated vessels sparged with nitrogen.

(i) Stage One

The results are shown in Table 6 and Fig. 4. The first stage cementation gave reproducible results with the Cu concentration falling to 5 mg/L after 20 min retention time and remaining at 5 mg/L with up to 30 min retention time. It is significant that the consumption of HCl (as measured by the solution pH) was negligible and that Cu did not re-dissolve with increased retention time (reaction [5]) as had been experienced previously (6). The equivalent Fe surface area at 1300 kg/tonne was calculated to be 1.7×10^2 m^2/tonne.

(ii) Stage Two

The second stage of cementation at 50°C indicated the importance of surface area on the final Cu concentration. Under similar feed conditions of approximately 5 mg/L Cu and pH 1, only the highest addition level of Fe dust (6.2 kg Fe/tonne concentrate) was successful in meeting the process Cu specifications of <1 mg/L. The calculated Fe surface area at 6.2 kg Fe (Atomet 67)/tonne concentrate was 1.6×10^2 m^2/tonne. As shown in Fig. 5, the Cu concentration fell rapidly to 0.9 ppm in 5 min and remained at this level for up to 30 min retention time. No re-solution of cemented copper was experienced and no significant consumption of HCl occurred.

(e) Reagent Consumption and Costs

Fe consumption was greatest during stage one, where over 98% Cu was cemented out of the leach liquors. From 9.3 to 12.3 kg/tonne Fe dissolution occurred, which corresponds to a stoichiometric Fe excess (based on Cu) of from 1.34 to 1.79. No trend was evident for increased Fe dissolution with decreased pH (2.0 to 0.31). The stage one excess iron consumption may be

Table 6. Two-Stage Fe Cementation at 50°C, pH 1

Stage 1 Cementation						Stage 2 Cementation					
Cement Agent		Cemented Solution				Cement Agent		Cemented Solution			
Type	Addition/tonne kg concentrate	Cu mg/L	Fe^{+3} mg/L	Retention time min	pH	Type	Addition/tonne kg concentrate	Cu mg/L	Fe^{+3} mg/L	Retention time min	pH
Fe wire	1300	1430	200	0	1.1	Fe powder*	6.2	5	600	0	0.82
		320	-	5	-			0.9	-	5	-
		70	-	10	-			0.8	-	10	-
		14	-	15	-			0.8	-	15	-
		5	-	20	-			0.8	-	20	-
		5	600	30	0.82			0.8	500	30	1.01
Fe wire	1300	1430	200	0	1.1	Fe powder*	3.1	5	800	0	n.a.
		270	-	5	-			2	-	5	-
		42	-	10	-			2	-	10	-
		5	-	15	-			2	-	15	-
		2	-	20	-			2	-	20	-
		5	800	30	n.a.			2	600	30	0.92
Fe wire	1300	1430	200	0	1.1	Fe powder*	1.6	4	400	0	1.18
		460	-	5	-			3	-	5	-
		87	-	10	-			4	-	10	-
		16	-	15	-			3	-	15	-
		5	-	20	-			3	-	20	-
		4	400	30	1.18			3	700	30	1.2

*Atomet 67
n.a. = not available

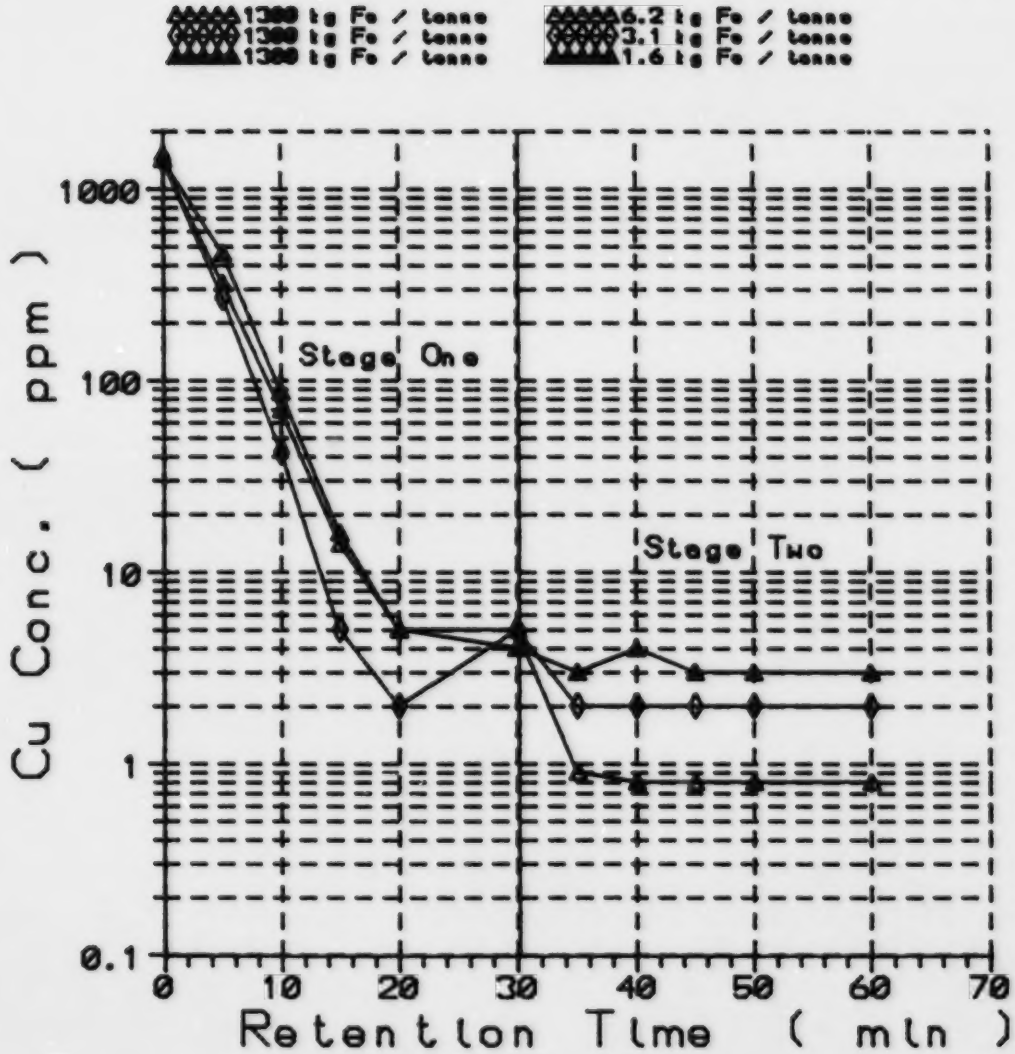

Figure 5. Two-Stage Fe Cementation, pH 1.0

related to reaction [3], the reduction of Fe^{+3} with Fe. In stage two, about 0.5 g/L Fe was solubilized for an overall two stage Fe dissolution of 12.3 to 15.4 kg/tonne. Over two stages the excess Fe consumption was 1.6 to 2.0 kg Fe/kg of Cu. The Fe consumption compares favourably with the published data of from 1.5 to 2.5 kg Fe/kg of Cu (7). As mentioned previously, the two stage iron cementation did not consume appreciable quantities of acid.

It is anticipated that the first and second stage reactors will operate at a fixed charge weight of iron. The iron reagent costs will be therefore equivalent to the iron dissolution of from 12.3 to 15.4 kg Fe/tonne concentrate.

The estimated reagent costs for the two-stage Fe cementation were as follows:

Table 7. Cost Estimates*

Reagent	Consumption kg/tonne conc	Cost >/kg Zn
Scrap**	12.3	0.43
Powder***	3.1	0.70
Total Cost		1.13

*100,000 tonnes Zn produced annually from Bulk Concentrate
**Scrap Fe, $100/tonne, F.O.B., Montreal, Jan. 1987
***Fe powder, Atomet 67, $640/tonne, F.O.B., Tracy, Québec, Jan. 1987

As shown in Table 7, over 61% of the reagent costs were attributed to the purchase of Fe powder. Future work, both bench and pilot scale should be directed towards greater scrap iron utilization, such as a stage two cementation using scrap.

CONCLUSION AND RECOMMENDATIONS

The recovery of Cu and Ag from chloride leach liquors was studied in batch cementation tests using iron. In stage one, Cu and Ag concentrations were reduced from about 1250 and 33 mg/L respectively, to <15 mg/L Cu and <1 mg/L Ag, under the following preferred conditions:

Stage One: 50°C, dynamic mixing, N_2 sparging
925 kg iron (wire)/tonne concentrate
Solution pH, $0.5 \leq pH \leq 1.5$
Retention time: 20 min

The Cu cementation was influenced by pH, with lower Cu concentrations achieved at higher pH. The <1 mg/L Cu and Ag (each) specification could not be achieved even at pH 2.0 (2 mg/L Cu) which necessitated a second stage cementation.

In stage two, the Cu and Ag concentrations were reduced from <15 mg/L and <1 mg/L, to <1 mg/L Cu and <0.5 mg/L Ag under the following conditions:

Stage Two: 50°C, dynamic mixing, N_2 sparging
6.2 kg iron (powder)/tonne concentrate
Solution pH, $0.5 \leq pH \leq 1.5$
Retention time: 20 min

As in stage one, the lowest Cu and Ag concentrations in stage two were obtained at the higher pH. Cd was not cemented out from the leach liquor.

The process utilized iron wire (considered the metallurgical equivalent of high quality scrap) and a commercially available iron powder. The surface areas, corresponding to the above conditions were 1.3 and 1.6 x 10^2 M^2 of iron surfaces/tonne concentrate. Within the pH range, $0.5 \leq pH \leq 1.5$, the acid consumption was negligible and iron dissolution was 15.4 kg/tonne

concentrate. Based on Cu, the iron consumption was 2.0 kg Fe/kg Cu and compared favourably with industrial consumption of 1.5 to 2.5 kg Fe/kg Cu. The iron reagent costs were estimated at >1.1 kg Zn.

The stage one cement product contained 54.1% Cu, 2.10% Ag, 0.39% Fe and significant amounts of As and Sb. The stage two cement, for recycle to stage one, contained 83.3% Fe, 0.99% Cu and 0.2% Ag. The stage one cement product would probably be acceptable as copper smelter feed, although the As and Sb content may be of concern.

The optimization of iron reagent consumption, and improvement of the cement product quality (with respect to As and Sb) will require additional bench scale evaluation. It is recommended that the cementation process be verified in a continuous pilot plant. Kennecott cone type reaction vessels using scrap iron and Outokumpu fluidized bed reaction vessels using iron powder, may be appropriate choices for the continuous pilot scale cementation.

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